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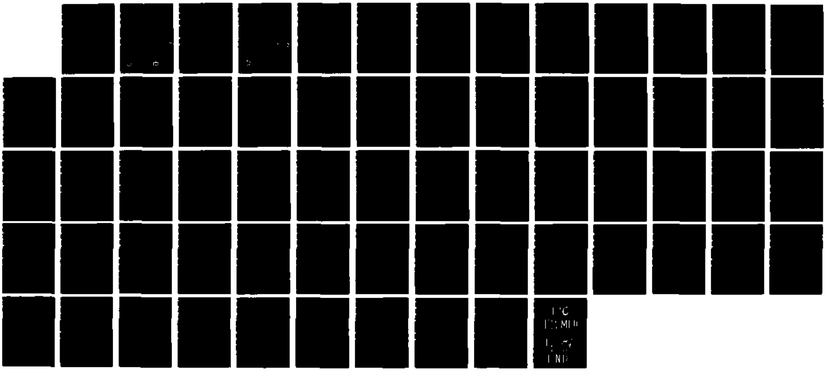

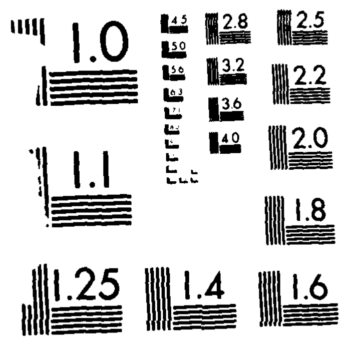


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OLD DOMINION UNIVERSITY
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# WATER QUALITY MONITORING AT DAM NECK AND NORFOLK DISPOSAL SITES

By

Raymond W. Alden III, Principal Investigator

and

Arthur J. Butt, Co-Principal Investigator

Final Report
For the period ending December, 1984



Prepared for the
Department of the Army
Norfolk District, Corps of Engineers
Fort Norfolk, 803 Front Street
Norfolk, Virginia 23510

Under
Contract DACW65-81-C-0051
Work Order No. 19





US Army Corps
Of Engineers
Norfolk District

February 1985

Report B- 39

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

ADA 165 192

# REPORT DOCUMENTATION PAGE

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION<br>Unclassified | 1b. RESTRICTIVE MARKINGS |
| 2a. SECURITY CLASSIFICATION AUTHORITY<br>2b. DECLASSIFICATION / DOWNGRADING SCHEDULE | 3. DISTRIBUTION / AVAILABILITY OF REPORT<br>Approved for public release, distribution unlimited. |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S) | 5. MONITORING ORGANIZATION REPORT NUMBER(S)<br>B-39 |
| 6a. NAME OF PERFORMING ORGANIZATION<br>Old Dominion University, Applied Marine Research Laboratory<br>6b. OFFICE SYMBOL (If applicable) | 7a. NAME OF MONITORING ORGANIZATION<br>U.S. Army Corps of Engineers, Norfolk District |
| 6c. ADDRESS (City, State, and ZIP Code)<br>Norfolk, VA 23508 | 7b. ADDRESS (City, State, and ZIP Code)<br>Norfolk, Virginia 23510-1096 |
| 8a. NAME OF FUNDING / SPONSORING ORGANIZATION U.S. Army Corps of Engineers, Norfolk District<br>8b. OFFICE SYMBOL (If applicable) NAOPL; NAOEN | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER<br>DACW65-81-C-0051 |
| 8c. ADDRESS (City, State, and ZIP Code)<br>Norfolk, Virginia 23510-1096 | 10. SOURCE OF FUNDING NUMBERS<br>PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT ACCESSION NO. |

11. TITLE (Include Security Classification)
Water Quality Monitoring at Dam Neck and Norfolk Disposal Site

12. PERSONAL AUTHOR(S)
Alden, R. W., III and A.J. Butts

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (Year, Month, Day) | 15. PAGE COUNT |
|---|---|---|---|
| Final | FROM ______ TO ______ | 1985, February | 47 |

16. SUPPLEMENTARY NOTATION

| 17. COSATI CODES | | |
|---|---|---|
| FIELD | GROUP | SUB-GROUP |
| | | |
| | | |

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
water quality, monitoring, Dam Neck Disposal Site, Norfolk Disposal Site, open ocean disposal, spatial-temporal variability, trend assessment, Chesapeake Bay plume, chlorophyll

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Report recommends that chlorophylls, dissolved oxygen and suspended solids loads be monitor to account for natural sources of variation (seasonal, depth, and geographic effects) and t allow the detection of any potential impacts associated with operations at DNDS before the become excessive.

| | |
|---|---|
| 20. DISTRIBUTION / AVAILABILITY OF ABSTRACT<br>☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS | 21. ABSTRACT SECURITY CLASSIFICATION<br>Unclassified |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL<br>Craig L. Seltzer | 22b. TELEPHONE (Include Area Code) (804) 441-3767/827-3767<br>22c. OFFICE SYMBOL NAOPL-R |

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
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SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

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Submitted by the
Old Dominion University Research Foundation
P. O. Box 6369
Norfolk, Virginia 23508

February 1985

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# WATER QUALITY MONITORING AT DAM NECK AND NORFOLK DISPOSAL SITES

By

Raymond W. Alden III* and Arthur J. Butt**

## INTRODUCTION

The continual dredging of navigational channels in major seaports is essential to maintain shipping operations. However, the disposal of potentially contaminated dredged materials raises environmental issues. Current methods for dredged material disposal include: landfill, onshore, and open ocean disposal. Available land for onshore and landfill disposal is often at a premium in the industrialized, urban seaport and may present a variety of social, economic, and ecological problems.

Recently, renewed interest has been generated in the feasibility of the open ocean disposal of dredged materials. Currently, dredged materials from the Hampton Roads Harbor area are being disposed at the Craney Island containment facility. However, Craney Island has a finite capacity in its current configuration. An open ocean disposal site designated the Norfolk

*Director, Applied Marine Research Laboratory, Old Dominion University, Norfolk, VA.

**Operations Manager, Applied Marine Research Laboratory, Old Dominion University, Norfolk, VA.

Disposal Site (NDS) is being considered as an alternative for some of the Norfolk Harbor system dredged material. The present on-going study involves the monitoring of baseline water quality characteristics at the NDS. This study was undertaken to characterize the magnitude of natural spatial-temporal variability of various ecological parameters and to develop a series of multi-variate statistical models to be used as an "early warning system" in historic trend assessment studies. This report presents the results of the 1984 baseline water quality programs at the Dam Neck and Norfolk Ocean Disposal Sites.

The water quality monitoring program at the Norfolk Disposal Site has continued for four years. The results of the first three years (1981-1983) have been reported previously (Alden *et al*., 1984). This report represents an update on the 1984 studies, as well as an evaluation of the findings of a more intensive one year study at the Dam Neck Site. Water quality patterns at the two sites are compared and those at the Dam Neck Site are examined in detail.

# STUDY AREAS

## Norfolk Disposal Site

The proposed Norfolk Disposal Site (NDS) delineated as a circle with a 4nm (7.4 km) radius is located beyond the 10 fathom contour line approximately 27 km east of Chesapeake Bay mouth (Fig. 1). The water flow pattern in this region of the middle Atlantic Bight is variable (Beardsley and Boicourt, 1980; Boicourt, 1981). The flow pattern on the continental shelf is typically southward (Bumpus, 1973) with the shallower inner shelf dominated by wind driven forces (Boicourt and Hacker, 1976; Boicourt, 1981). Near estuarine influences, the flow patterns are more complex. More specifically, the flow pattern at the Chesapeake Bay mouth/continental shelf interface and seaward is very dynamic. Circulation at the interface is in response to the synergistic interactions of river runoff, vertical decoupling at the pycnocline, wind and tidal prism patterns (Boicourt and Hacker, 1976; Wang, 1979; Boicourt, 1981; Johnson *et al*., 1983). The annual outflow of freshwater from Chesapeake Bay accounts for over 50% of the freshwater inflow to the Mid-Atlantic Bight (Beardsley *et al*., 1976).

Short-term disruptions to routine flow patterns around the Bay mouth are common. Wind forcing of the shelf waters affects the nontidal flow through the Bay mouth. Bottom waters further than 20 km east of the Bay mouth were reported to flow towards the Bay with prevailing southerly winds during the summer, whereas the

inner shelf surface waters showed a northward drift (Boicourt, 1981). However, strong winds can produce outflow or inflow surges. Boicourt (1973), reported at 10% volume reduction in Chesapeake Bay over 48 hours resulting in an outflow surge extending far offshore.

Nine stations were monitored for water quality parameters at the proposed disposal site from 1981 through 1984 (Fig. 1). A central station, #5 (36° 59' N and 75° 39' W) and eight additional stations were located at the cardinal points to Station 5: four stations (16, 11, 8, 3) were located at a 2 nm (3.7 km) radius from the center and the remaining four (14, 13, 6, 1) were placed 1 nm (1.85 km) beyond the NDS boundary or 5 nm north, south, east and west of center. The depth of NDS varied from 16 m (52 ft) to 26 m (85 ft).

## Dam Neck Disposal Site

The Dam Neck Disposal Site (DNDS) activated in 1968, is an interim open-water site approximately 3 miles east of Dam Neck, Virginia (Fig. 2). It receives dredged material from Cape Henry Channel and the Thimble Shoal Channel. The area is described as a high energy zone just south of the Chesapeake Bay mouth, and is between the 30 and 50 ft (9.2 to 15.4 m) contour lines.

The majority of outflowing surface water from the Bay travels towards the south along the Atlantic Ocean Channel just east of DNDS. A strong density stratification is identified in

the area. The low salinity surface water is characterized as part of the Chesapeake Bay Plume during the warmer months. This effect is minimized during the winter when vertical mixing is greatest. The southerly drift of shelf water combined with the local Bay plume dominates advective transport in the region. Wind strength and direction serve as strong influences on water flowing out of the Bay and along the coast line. Onshore and osshore surface transport conditions occur between southerly drift occurrences due to daily and/or seasonal trends.

Water quality is generally considered good according to the Virginia State Water Control Board Standards (VSWCB). The only exception is the depressed hypolimnion dissolved oxygen (DO) concentrations peridocially reported by VSWCB (personal communication 1984). Surface waters are generally near saturation levels (6 mg/l); however, DO has been reported as low as 4.6 and 5.0 mg/l during 1973 (Hydroscience, 1974). Depressed DO levels have been reported from bottom samples offshore of Rudee Inlet and North Bay to Cape Henry from 1981-1983.

An intensive water quality monitoring program was conducted at the DNDS from the Fall of 1983 to the Fall of 1984. Five stations were established to monitor the water quality patterns of the region. Originally, the sampling regime was established to represent a fan-shaped pattern with a transect of stations on either side of a "submerged bar" extension of the DNDS (see Parker, 1983 for details of the bar concept). After the study was initiated, the Norfolk District of the U.S. Corps of Engineers

decided that the bar extension concept would not be used and that the DNDS would remain in its current configuration. However, in order to maintain continuity in the monitoring program, the station locations were retained. The fan-shaped pattern is also believed to effectively sample the characteristics of the Bay Plume in the region. The southern-most stations of the fan straddle the northern extent of the DNDS.

# METHODS AND MATERIALS

## Field and Analytical Methods

The 1983-1984 water quality monitoring program at NDS maintained the seasonal (quarterly) collection regime developed during the previous years of the study. Collections at DNDS were made monthly since an equivalent data base has not been established for this region. Monthly cruises were also considered necessary because it was believed *a priori* that DNDS would have more dynamic water quality patterns than NDS due to the direct influence of the Bay Plume. Duplicate water samples were collected at 1 m below the surface and 1 m above the bottom in 5 or 8ℓ teflon-lined go-flo bottles on a rosette sampler. Aliquots were withdrawn from the go-flo bottles and nitrite ($NO_2$-N), nitrate ($NO_3$-N), ammonia ($NH_3$-N), total Kjeldahl nitrogen (TKN), orthophosphates ($OPO_4$), total phosphorous (TP), chemical oxygen demand (COD), pH, turbidity, suspended solids (SS), volatile nonfilterable residue (VNR), and chlorophylls (*a*, *b*, *c*, phaeophytin *a*) were determined.

Field measurements of temperature ($^oC$), salinity ($^o/oo$), and dissolved oxygen (DO) were monitored at a surface and near bottom depth at each station by portable field meters. The DO meter was calibrated against a Winkler titration.

Chlorophyll *a*, *b*, *c* and phaeophytin *a* were measured and calculated by the UNESCO method (Strickland and Parsons, 1974). Suspended solids and volatile nonfilterable residues were determined by drying the samples to a constant dry weight and

subsequently ashing the samples (APHA, 1975).

Nitrate levels were determined by the cadmium reduction method, and nitritees were analyzed by the sulfanilic acid method (APHA, 1975). Total and orthophosphate concentrations were determined by ammonium molybdate and potassium antimonyl tartrate reactions with The orthophosphates. Samples analyzed for total phosphates were first digested by the persulfate method to oxidize all forms of phosphorous to the orthophosphate form (APHA, 1975). Total Kjeldahl nitrogen and ammonia samples were steam distilled and processed by nesslerization (APHA, 1975). Chemical oxygen demand (COD) was performed by a modified Hack (1981) procedure in which samples were diluted to $20^{o}/oo$ salinity and treated with $HgSO_4$ to reduce chloride interference.

## Statistical Methods

Computer based, multivariate analytical techniques were employed to characterize the spatio-temperal water quality characteristics of the disposal sites. The general philosophy of the use of the baseline statistics and their empirical application for NDS have been discussed previously (Alden, 1984; Alden et al., 1984). As with the previous baseline studies, the interpretation of the findings emphasize only those trends that are highly significant ($p<0.01$) or are recurrent. This convention has been adopted for a number of reasons associated with baseline statistics (ibid).

Multivariate analysis of variance (MANOVA) models compared 1984 water quality data from NDS to the patterns observed in the data base assembled for the previous three years. MANOVA models were also used to compare the water quality patterns at NDS with those observed concurrently at DNDS.

In order to explore the spatio-temporal water quality trends at DNDS in more detail, a principal components analysis (PCA) was employed to reduce the data set. As a result, relatively few factors retain most of the information concerning significant patterns. The PCA factors were plotted for presentation of overall temporal trends (i.e. ordination). The PCA scores for each factor were also entered into a series of multiple regression analysis models which designed to examine the significance of specific spatio-temporal effects. The effects of depth, station location, month to month variations, and the appropriate interactions were explored for each of the major PCA factors. The station locations were assigned values as to position north to south (NS) and west to east (WE) and were entered into the models as covariates. The data set was divided into seasonal subsets and the monthly effects within any season were allowed to take linear or nonlinear patterns. Depth was treated as a binary dummy variable with values of 0 for surface and 1 for bottom measurements. The multiple regression methods used have been described by Kim and Kohout (1975).

In addition to the characterization of spatial-temperal baseline patterns, the water quality at DNDS involved the development of statistical techniques for the estimation of levels of

"minimum detectable impacts" (MDI's): those levels of change in any given variable which would be required to define a statistical difference during trend assessment studies. The philosophical concept of the MDI's and the methods for the calculation of various MDI models have been detailed previously (Alden, 1984; Alden et al., 1984). The MDI's were calculated for each variable for single samples, and for data sets employing seasonal and season-area interaction models.

# RESULTS AND DISCUSSION

## Spatio-Temporal Patterns at NDS

The four years of water quality data from NDS are presented in Figs. 3-6. Table 1 presents the results of the statistical comparison of the 1984 DNDS data with the previously collected data. Most of the water quality patterns seen during 1984 match trends observed during previous years, although some differences were noted.

Thermal stratification was maximum during the summer as during previous years (Fig. 3a). Salinities were lowest during the spring months, corresponding to periods of greatest stratification (Fig. 3b). Surface salinities were depressed (as low as 25 ppt) due to an extension of the Chesapeake Bay influence offshore. The buffering capacity of the marine system held pH readings near 8, except that values were slightly lower in the spring and higher throughout the rest of the year (Fig. 3c). Dissolved oxygen levels were generally inversely related to water temperature (Fig. 3d). Peaks of oxygen also correspond, to a degree, to chlorophyll peaks in the fall and early spring, particularly the large peak in May of 1984 (Fig. 5, Table 1). The vertical patterns of oxygen content indicated that oxygen depletion of bottom waters was never a problem at NDS. In fact, oxygen readings were often near saturation levels and bottom oxygen measurements were not significantly below surface concentrations (Fig. 3, Table 1).

The indices of materials suspended in the water column generally exhibited low values, but showed seasonal trends (Fig. 4). Lowest levels of SS, VNR and COD were generally found during the spring and summer, except during May of 1984 when all values were elevated (Table 1). Highest values of SS, VNR and turbidity were generally found in bottom waters, particularly during peak periods. The COD values for 1984 were all elevated, especially the summer reading. The significance of this trend is uncertain since the analytical technique for marine samples is somewhat developmental.

The nutrients in the waters around NDS were quite low, often at levels below detection limits (Fig. 5). Seldom were there indications of significant vertical stratification (Table 1). The 1984 nutrient concentrations were generally somewhat higher than those from previous years. Nitrites, nitrates and ammonia peaked in May of 1984, during a dynamic period of spring bloom. Orthophosphates were below detection limits for this period, although total phosphorous values were quite high, probably associated with the algal biomass. Ammonia levels were quite low throughout the study, with highest levels generally found during the winter and lowest values in the winter. The major exception was a peak during the same 1984 spring cruise.

Chlorophyll content of the waters of NDS were moderately low, but followed an expected seasonal pattern (Fig. 6). Chlorophyll a and c were generally highest in the Fall and lowest

in the summer months. Chlorophyll *b* values were much lower and did not exhibit any distinct seasonal pattern. All chlorophylls were higher in 1984 and peaked during the May cruise. This period was virtually the only time that the chlorophyll levels in surface waters significantly exceeded those observed in bottom waters. Phaeophytin values were generally quite low throughout the study, particularly in 1984.

## Spatio-Temporal Patterns at DNDS

The water quality data from DNDS are summarized in Figs. 7-10. Table 2 presents the results of a MANOVA comparison between the 1984 DNDS and NDS data. Temperature patterns at DNDS were very similar to those observed from 1981 to 1984 at NDS: minimum temperatures were observed in January and maximum readings were seen in early fall (Fig. 7a). The maximum period of thermal stratification was in mid-summer and surface to bottom temperature differences disappear in the winter. Although DNDS waters were always significantly warmer than those of NDS, the average differences were only a matter of 1-2 degrees (Table 2).

Salinities at DNDS were generally a few parts-per-thousand (ppt) lower than the more offshore NDS (Fig. 7b, Table 2). The maximum differences in salinities between the two sites were observed during the spring cruise. This is a period when the outflowing freshwaters of the Bay significantly influence surface salinities at DNS. Station values dropped nearly 10 ppt below the rather stable salinities of the bottom waters. Dissolved oxygen

values peaked during the winter months when temperatures and salinities were low and again during the period of spring bloom (Fig. 7c). Minimum oxygen levels were found during the mid-summer months in surface waters and in late summer in bottom waters. The bottom waters averaged approximately 5 mg/l during this minimum oxygen period. As with NDS the pH of the DNDS stations were quite stable throughout the study, with minimum values occurring during early spring (Fig. 7d).

The indices of suspended materials followed the same basic patterns observed at the NDS, but were generally more exaggerated (Fig. 8; Table 2). Highest values of suspended solids and turbidities were observed were observed in the fall and later summer, especially in the bottom waters (Table 2). Lowest values of these parameters were during the early summer. The two indices of organic matter (COD and VNR) had relatively high levels during the spring months.

The nutrients at the DNDS exhibited basically the same patterns as observed at NDS, but most were somewhat elevated at these inshore stations (Fig. 9). Nitrites and nitrates were higher during the fall and winter months and were lower during the summer. During periods of maximum concentrations, the surface values were significantly higher than the bottom waters. This phenomenon was not too surprising, considering the impact of the Bay Plume on this area. As with NDS, ammonia peaked in the late fall and during the early spring. Orthophosphates peaked during the same period in the early spring. Samples from the November

cruise were lost, but the increase in September's values tended to indicate that it may exhibit a similar pattern: values which were higher during the fall, low in the summer and with a peak in the early spring. Total phosphorous exhibited a more continuous trend: higher in the fall and decreasing through the spring and summer. Both orthophosphates and total phosphorous tended to be found in greater concentrations in the bottom waters.

The somewhat elevated chlorophyll content of the water appears to represent the major difference between the DNDS and NDS stations during 1984 (Fig. 10; Table 2). All chlorophylls (a, b, c, and phaeophytin) peaked during the May cruise. However, the levels of the chlorophylls seen at DNDS stations were 2 to 3 times those observed at NDS. The chlorophyll a and c concentrations were greatest in the surface waters at DNDS and NDS, while chlorophyll b exhibited no signs of vertical stratification at either of the sites. It appears that the high chlorophyll levels in the surface waters of both sites represents a "spring bloom" associated with the pulse of nutrient-rich freshwaters of the Bay Plume during the spring months. The higher chlorophyll concentrations at the DNDS stations probably reflect their closer proximity to the Plume effects. High concentrations of chlorophyll a and c are indicative of rapidly growing populations of small diatoms typical of "bloom" conditions (Dr. H.G. Marshall, personal communication).

In order to summarize the water quality patterns at DNDS and to test local geographic patterns, a PCA was run on the water

quality data set (Fig. 11). The first four PCA factors accounted for nearly 65% of the variance in the data (23%, 17%, 15%, and 8%, respectively for factors 1 through 4). In ordder to present a visual summary of the overall water quality of representative seasonal data sets (i.e. winter, spring-surface, spring-bottom, summer and fall) were plotted on graphs of the principal axes: PCA 1 vs. PCA 2, PCA 1 vs. PCA 3, and PCA 1 vs. PCA 4. The PCA factor 1 represented the changes in chlorophylls and oxygen in a positive direction and temperature and salinity in a negative direction (Fig. 11a). The second factor (PCA 2) was positively correlated with suspended solids, volatile residues, salinity, turbidity and ammonia. The PCA 3 values were positively associated with temperature, suspended solids, TP, TKN and pH and negatively associated with dissolved oxygen (Fig. 11b). PCA 4 was positively correlated with salinity and negatively correlated with nitrite-nitrates (Fig. 11c).

Starting with the winter season (i.e. February), oxygen, chlorophylls, suspended solids, turbidity and the nitrogen based nutrients ($NO_2$, $NO_3$, $NH_3$) are moderately high while temperatures are low.

Moving into the spring months (i.e. May), temperatures went up and salinities dropped in the surface waters as the Bay Plume pulsed into the area. Chlorophylls increased dramatically in the surface waters and the increase in primary productivity led to elevated dissolved oxygen levels and pH readings, as well as high measurements for the organic load indices (e.g. VNR, COD). At the

same time, nutrients appeared to have been somewhat depleted by the bloom as both nitrogen and phosphorous-containing compounds decrease in concentration.

Temperatures and salinitities rise as chlorophyll and oxygen levels drop during the summer months. Suspended solids and turbidities increase, particularly in the bottom waters, nitrogenous nutrients such as nitrites, nitrates and ammonia were low, while TKN values peaked. Total phosphorous values increased, as did the orthophosphates in bottom waters. It appears that summer is a period of low nutrients and productivity. Most of the nitrogen and phosphorous appears to be tied up in organic matter, although there are indicators of remineralization of phosphates in the bottom waters.

The fall samples (i.e. November) exhibited moderate temperatures and high salinities. This was the period of least stratification but the greatest levels of suspended solids, VNR, turbidity, and ammonia. Fall in this region is characterized by rough weather conditions which breaks down the stratification of the Plume and stirs up the suspended solid load in the water column.

The more dynamic Dam Neck study area generally displayed a greater degree of station to station variation than did NDS. This trend is apparent by the relatively larger standard error bars seen for some of the DNDS seasonal data points in comparison to those plotted for the same variables sampled at NDS.

In order to explore whether the station to station variation

represents significant geographic patterns in the region, a series of multiple regression models were run on the major PCA factors (Table 3). As would be expected, linear or nonlinear month to month effects most often accounted for most of the variation in the data. Depth effects were also consistently seen to explain a portion of the variance for most of the PCA factors. The month to month and depth effects have already been discussed (Figs. 6-10). The major geographic trend, which was particularly apparent during the spring and summer months, involved inshore-offshore differences in water quality. Factors associated with chlorophylls, suspended solids, TP, TKN, nitrate-nitrites were always inversely related to the WE effect, especially for the bottom waters. Thus, the bottom waters of the inshore leg of the sampling pattern were consistently and significantly enriched compared to the offshore stations. On the other hand, temperatures, salinities and dissolved oxygen levels were greater in the waters of the offshore stations. The north-south pattern along the transects was seldom seen to produce a significant effect on the PCA factors.

These patterns tend to parallel the trends found during an intensive study of dissolved oxygen concentrations in the vicinity of the Atlantic STP diffuser discharge and the DNDS (Alden and Butt, 1985). A grid of 13 stations were sampled semi-monthly during the summer months and the oxygen patterns were "mapped" by a regression model. Oxygen levels were lowest in inshore bottom waters. It was speculated that clockwise eddies deposit organic-

rich materials from the Bay Plume into inshore bottom waters and that the elevated levels of these oxygen demanding materials reduce the oxygen levels. The results from the present study tend to confirm a similar trend, where the bottom waters of the inshore stations were more enriched and contained lower oxygen levels than the offshore stations. The waters of the Bay Plume have been previously shown to be enriched in nutrients, suspended solids, and even sewage-associated organic matter (Brown and Wade, 1981; Brynes and Oertel, 1980; Gingerich and Oertel, 1981; Robertson and Thomas, 1981). Materials in this enriched plume not only stimulate the "spring bloom" observed in the coastal surface waters, but also appear to concentrate in the inshore bottom waters in comparison to the more offshore stations. Of course, the separation of the 5 stations sampled during the present study did not cover a great portion of coastal area which is potentially impacted by the Bay Plume. Therefore, it is difficult to determine whether the inshore-offshore pattern extends over a large coastal region and produces more significant effects outside of the study area.

Despite the geographic patterns observed in the study area, it should be noted that the water quality of even the more "enriched" month/station/depth combinations was not seen to be extreme when compared to that observed for other estuarine and coastal regions. Kester and Courant (1973) and Kuo et al. (1975), reivew and summarize most of the water quality studies conducted in the Chesapeake Bay and nearshore coastal waters. The water

quality data from the present study falls within the range of values presented in these reviews. As might be expected, the water quality of the coastal waters of the DNDS study area was better than that found for local estuaries more directly impacted by man (VSWCB, 1976). Likewise, the water quality conditions in the vicinity of the DNDS study area appeared to be better than the coastal regions of the New York Bight which has been reported to have periods of intense eutrophication and extreme hypoxia. However, the "spring bloom" chlorophyll a levels at the DNDS stations did exceed 40 μg/l, which has been viewed by the U.S. Environmental Protection Agency and the Virginia State Water Control Board as the maximum desirable level for the prevention of eutrophication (Robert Jackson, VSWCB, 1977, Special Report on the Elizabeth River, Virginia). The oxygen levels in the bottom waters also dipped below the 5.0 mg/l level previously recommended for the protection of marine ecosystems (EPA, 1978) and well below the 6.0 mg/l level recently adopted by the State of Virginia for the protection of marine and estuarine and biota (Amendments to Water Quality Standards pursuant to Section 62.1-44.15(3) of the Code of Virginia, effective October, 1984). Therefore, even though the water quality of coastal waters in the vicinity of the DNDS stations is not nearly as bad as that of certain areas of the Chesapeake Bay or the coastal waters to the north, some concern should be expressed over the seasonal patterns observed in the region.

## Minimum Detectable Impacts in Water Quality at DNDS

In order to define the levels of change which might represent "statistically significant" effects under the context of natural spatio-temporal variability, minimum detectable impacts (MDI's) were calculated for each variable in the seasonal data sets (Table 4) (see Alden, 1984; Alden et al., 1984 for details of the philosophy and methods of calculating MDI's). The MDI's ranged from less than a 5% change for parameters exhibiting low variability to over 1000% for the most variable parameters. However, the parameters with the largest MDI's were generally those with concentrations very near to the detection levels. Therefore, the absolute values of the parameters resulting from the hypothetical "impacts" at the DNDS (relative to the water quality at Stations 10, 1 and 13 to the north) were not generally extreme in a ecological sense. Even the "impacted" values calculated for single samples were quite moderate for most parameters, despite the fact that the level of change must be greater for statistical detection when only one post-impact sample is observed. However, dissolved oxygen readings must drop to below 4 mg/l before statistical detection of geographic patterns associated with DNDS operations would be possible. Should DNDS operations increase greatly, perhaps a more intensive trend assessment monitoring regime should be considered for DO, so that the degree of replication (and geographic coverage) would allow a more sensitive statistical evaluation of bottom DO patterns in the study area.

It must also be noted that the direction of (impact) change for the calculation of the MDI's for chlorophylls was chosen to be negative to represent inhibition or toxicity to the phytoplankton communities. This choice was made to maintain continuity with the MDI's previously calculated for the NDS area (Alden <u>et</u> <u>al</u>., 1984). However, the absolute values of the percent changes indicated in Table 4 can also be taken to indicate the degree of increase required for statistical detection. Thus, an increase in chlorophyll values of 2 to 3 times (200-300%) would be required before the trend could be considered statistically significant ($p<0.001$). The fairly large level of change required for statistical detection can be attributed to the fairly large degree of variation due to depth effects (i.e. surface chlorophyll readings were different from bottom values within any given season) and, to a lesser degree, due to geographic effects. Thus, the mean chlorophyll <u>a</u> value (surface and bottom values combined) of a post-impact spring cruise to the DNDS stations would have to exceed the average spring values observed in the present study by a factor of 2 to 3 times before statistical detection would be possible. Considering the rather high levels of chlorophyll <u>a</u> already seen for the "bloom" conditioning in the surface waters of the region, the prudent approach to any future baseline or trend assessment studies may be to expand the chlorophyll monitoring regime (i.e. more replicates, more geographic coverage) in order to detect changes before excessive levels of eutrophication can occur in the surface waters of the DNDS.

One final point should be made concerning the MDI's. The *a priori* statistical level of the MDI's was selected to be $\alpha$=0.001 for reasons which have been previously discussed in detail (Alden, 1984; Alden *et al*., 1984). However, if a lower level of statistical certainty were employed (e.g. $\alpha$=0.05), the MDI's and, consequently, the degree of change required for statistical detection would decrease dramatically. As an example, Table 4 presents a series of MDI's for the summer season which were recalculated for a level of $\alpha$=0.05. The MDI's (% change) observed for the lower level of statistical certainty were considerably lower from the $\alpha$=0.001 criteria. Therefore, if a number of "false alarms" are considered to be acceptable for a trend assessment program, then the lower MDI's may be considered to be indicative of the level of statistical detectability in future studies. Of course, the MDI's only provide an indication of the degree of statistical detectability assuming that natural conditions do not significantly deviate from the baseline. This assumption is somewhat questionable until an adequate baseline data base has been assembled to account for the full range of natural variations to be expected in any given study area (see Alden *et al*., 1984).

## SUMMARY AND CONCLUSIONS

In 1984, a fourth year of baseline water quality monitoring was conducted at NDS and a new baseline program was implemented at DNDS. Both of the monitoring programs were designed to develop a data base against which future water quality data can be evaluated once the dredged material disposal site becomes active (or in the case of DNDS, more active). The major goals of the programs were threefold: 1) to provide a characterization of the natural water quality patterns at the sites; 2) to develop and continually update multivariate statistical models allowing the detection of future environmental trends which are significantly different from natural patterns; and 3) to estimate the minimum levels of statistically detectable change in each parameter (MDI's) as a mechanism for the evaluation of the effectiveness of the program.

The 1984 water quality data from NDS appeared to generally reflect the seasonal patterns observed during 1981 to 1983 baseline studies. The water quality at the NDS can be characterized as being quite good. Most of the nutrients were low and many were below detection limits throughout much of the baseline studies. In general, the 1984 data differed from the previously reported patterns for NDS in that there were indications of a strong "spring bloom" associated with an apparent influx of Bay plume waters into the area. Chlorophylls, suspended materials, and most nutrients were elevated during this period in comparison to data from previous years.

The overall seasonal water quality patterns at the DNDS were quite similar to those observed for NDS. However, the levels of the various water quality parameters clearly indicated a greater influence of the Bay plume on the DNDS stations: temperatures were slightly higher; salinities were lower; the loads of suspended organic materials were higher; most of the nutrients were higher; and the chlorophyll content of the waters was significantly elevated, particularly during the "spring bloom" period. The latter characteristic and the low oxygen levels observed in the bottom waters of the DNDS stations in the late summer appear to represent the greatest differences in water quality between the two sites.

In addition to the obvious seasonal and depth related effects on water quality at DNDS, there appeared to be strong indications of a strong inshore-offshore trend, especially during the spring and summer months. The bottom waters of the inshore stations tended to be more enriched in nutrients, suspended/organic materials, and chlorophylls than those of offshore stations located a similar distance from the Bay mouth. Most importantly, perhaps, was the trend that the oxygen content of the bottom waters of inshore stations were lower than those of offshore stations. Based, in part, upon previous physical and sediment transport studies in the region, it appears that clockwise eddies from the Bay Plume enrich the bottom waters of the inshore stations and that the enrichment of oxygen demanding organic materials are responsible for the low oxygen conditions of this area. Although the water quality conditions of even the

inshore DNDS stations are clearly better than those observed for areas of the Chesapeake Bay or the coastal waters of the New York Bight, some environmental concern should be expressed over the seasonal and geographic patterns (particularly of chlorophylls and DO) which have been observed in this region. Unfortunately, long-term trends are difficult to predict when only one year of baseline data is available. Moreover, mechanisms of control/clean-up are unclear since the "source", at present, appears to be the Chesapeake Bay itself.

Minimum detectable impacts (MDI's) were calculated for each of the water quality parameters. Most of the MDI's for the DNDS water quality parameters were of moderate magnitude or represented changes that resulted in "impacted" values which were of little ecological concern. Therefore, the type of monitoring regime implemented would be expected to detect impacts statistically before the absolute levels would become environmentally detrimental. Therefore, the monitoring program in combination with the statistical models would appear to provide an effective "early warning system" for the detection of most water quality impacts which may be associated with disposal operations. However, it is recommended that chlorophylls, DO readings and possibly suspended solids loads be monitored more rigorously in order to account for the natural sources of variation (seasonal, depth, and geographic effects) and to allow the detection of any potential impacts associated with operations at DNDS before they become excessive.

## ACKNOWLEDGEMENTS

The authors wish to express their gratitude to the numerous support people who worked the long hours to accomplish the research. In particular, our thanks go to the Water Chemistry Laboratory workers, Susanne Jackman, Steve Sokolowski, Phyllis Friello, Theresa Breschell and John Cross. Also, we wish to especially thank the captain and crew of the NOAA vessel R/V *Laidly* and their support crew.

Thanks are extended to the operational staff of the Applied Marine Research Laboratory in particular, Jeff Hall and David Wade. Additional support was supplied by Sue Cooke from the Center for Instructional Development.

This work was supported by the Department of the Army, Norfolk District Corps of Engineers (Contract No. DACW65-8[illegible]-C-0051). It was through their confidence that so much was accomplished.

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TABLE 1. Results of MANOVA comparisons of year (1981-1983 vs. 1984) and depth (bottom vs. surface) effects at Norfolk Disposal Site (NDS). Values represent predicted values from the model and letter superscripts represent the effects that are significant at the α=0.01 level.

| | Fall | | | | Winter | | | | Spring | | | | Summer | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1981-1983 | | 1984 | | 1981-1983 | | 1984 | | 1981-1983 | | 1984 | | 1981-1983 | | 1984 | |
| Parameter | B | S | B | S | B | S | B | S | B | S | B | S | B | S | B | S |
| Temperature ($^{o}$C) | 14.5 | - | 11.6[a] | 11.3[c] | 4.3 | - | 4.0[a] | 4.0[a] | 11.7 | 13.9[b] | - | 13.9[b] | 19.5 | 22.5[b] | 18.4[a] | 21.4[ab] |
| Salinity (ppt) | 31.5 | 31.0[b] | 30.2[a] | 29.7[ab] | 31.8 | 31.5[b] | - | 31.5[b] | 29.6 | 27.1[b] | 29.0[a] | 27.0[abc] | 31.0 | 30.3[b] | 31.6[a] | 30.9[ab] |
| DO (mg/l) | 9.5 | - | - | - | 9.0 | - | 8.1[a] | 8.1[a] | 9.9 | - | 10.5[a] | 10.5[a] | 7.7 | - | - | - |
| pH | 8.0 | - | 8.1[a] | 8.1[a] | 7.9 | - | 7.7[a] | 7.7[a] | 7.7 | - | - | - | 8.0 | - | - | - |
| COD (mg/l) | 57 | - | 75[a] | 75[a] | 65 | - | 95[a] | 95[a] | 55 | - | 83[a] | 83[a] | 120 | - | 216[a] | 216 |
| Turbidity (NTU) | 1.1 | - | - | 1.3[c] | 1.0 | 0.8[b] | 0.8[a] | 0.6[ab] | 1.4 | 1.2[b] | 2.0[a] | 1.5[abc] | 1.3 | 1.1[b] | 1.5[a] | 1.3[ab] |
| $NO_2$ (μg/l) | 0.8 | 1.0[b] | 1.4[a] | 1.9[abc] | 0.8 | - | 1.1[a] | 1.1[a] | 1.4 | 2.0[b] | 2.2[a] | 3.1[abc] | 0.7 | - | 1.2[a] | 1.2[a] |
| $NO_3$ (mg/l) | 0.025 | - | - | - | 0.013 | - | 0.025[a] | 0.025[a] | 0.017 | 0.022[b] | .030[a] | .035[ab] | 0.007 | - | 0.013[a] | 0.013[a] |
| $OPO_4$ (mg/l) | 0.004 | - | .008[a] | .008[a] | 0.010 | - | 0.018[a] | 0.018[a] | .002 | .001[b] | .003[a] | .002[ab] | - | - | - | - |
| TP (mg/l) | 0.019 | - | 0.038[a] | 0.039[ac] | 0.014 | - | 0.020[a] | 0.020[a] | .022 | - | .035[a] | 0.035[a] | 0.020 | - | 0.030[a] | 0.030[a] |
| TKN (mg/l) | 0.176 | - | - | - | 0.201 | - | - | - | 0.281 | - | - | - | 0.204 | - | - | - |
| $NH_3$ (mg/l) | 0.081 | - | 0.094[a] | 0.094[a] | 0.076 | - | 0.018[a] | 0.018[a] | 0.180 | - | 0.268[a] | 0.268[a] | 0.030 | - | - | - |
| SS (mg/l) | 13.36 | - | 11.62[a] | 11.62[a] | 12.98 | - | - | - | 13.39 | 11.74[b] | 14.13[a] | 11.72[abc] | 11.69 | - | 10.32[a] | 11.12[ac] |
| VNR | 4.24 | - | 4.64[a] | 4.64[a] | 2.95 | - | 3.95[a] | 3.95[a] | 4.11 | 3.78[b] | 5.95[a] | 5.62[ab] | 3.34 | - | - | - |
| Chlorophyll a (μg/l) | 6.1 | - | - | 6.7[c] | 4.8 | 3.3[b] | 7.3[a] | 4.8[abc] | 4.2 | 7.0[b] | 7.3[a] | 12.9[abc] | 2.0 | 1.5[b] | - | 1.5[b] |
| Chlorophyll b (μg/l) | 0.3 | 0.4[b] | - | 0.4[b] | 0.3 | 0.2[b] | - | 0.2[b] | 0.5 | - | 0.7[a] | 0.7[a] | 0.2 | - | 0.1[a] | 0.1[a] |
| Chlorophyll c (μg/l) | 2.2 | - | 2.4[b] | 2.6[bc] | 1.9 | 1.4[b] | 2.7[a] | 1.9[abc] | 1.9 | 2.7[b] | 2.8[a] | 4.3[abc] | 1.0 | - | 0.6[a] | 0.6[a] |
| Phaeophytin (μg/l) | 0.1 | - | - | - | 0.4 | - | 0.0[a] | 0.0[a] | 1.0 | - | 1.5[a] | 1.5[a] | 0.5 | - | 0.2[a] | 0.2[a] |

| Fall | Winter | Spring | Summer |
|---|---|---|---|
| Multivariate model: | Multivariate model: | Multivariate model: | Multivariate model: |
| Year: F=1000.37(18,86); p<0.001 | Year: F=585.28(18,111); p<0.001 | Year: F=243.08(18,155); p<0.001 | Year: F=283.49(18,120); p<0.001 |
| Depth: F=9.99(18,86);p<0.001 | Depth: F=7.32(18,111);p<0.001 | Depth: F=26.89(18,155);p<0.001 | Depth: F=13.76(18,120);p<0.001 |
| Year x Depth: F=8.44(18,86); p<0.001 | Year x Depth: F=3.84(18,111); p<0.001 | Year x Depth: F=33.50(18,155); p<0.001 | Year x Depth: F=16.58(18,120); p<0.001 |

Notes: - Effect not different at the α=0.01 level (i.e. same as default value - 1981-1983 bottom; or zero if 1981-1983 value is not significant.
a) Year effect significant at the α=0.01 level.
b) Depth effect significant at the α=0.01 level.
c) Year x Depth effect significant at the α=0.01 level.

TABLE 2. Results of MANOVA comparisons of sites (DNDS vs. NDS) and depth (bottom vs. surface) effects. Values represent predicted values from the model and letter superscripts represent the effects that are significant at the $\alpha$=0.01 level. The values which are underlined are those believed to represent ecologically significant differences in water quality patterns.

| Parameter | December 1983 | | | | February 1984 | | | | May 1984 | | | | August 1984 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DNS | | NDS | | DNS | | NDS | | DNS | | NDS | | DNS | | NDS | |
| | B | S | B | S | B | S | B | S | B | S | B | S | B | S | B | S |
| Temperature ($^{o}$C) | 12.0 | - | 11.7[a] | 11.3[ac] | 4.5 | - | 4.1[a] | 3.8[ac] | 11.3 | 13.7[b] | 11.0[a] | 13.1[abc] | 19.8 | 22.1[b] | 18.4[a] | 21.6[abc] |
| Salinity ($^{o}$/oo) | 30.3 | 29.8[b] | - | 29.4[bc] | 29.7 | 27.8[b] | 31.8[a] | 31.6[abc] | 27.6 | 23.4[b] | 29.1[a] | 26.1[abc] | 29.3 | 27.8[b] | 31.6[a] | 31.1[abc] |
| DO (mg/ℓ) | 9.3 | 9.5[b] | 9.6[a] | 9.9[abc] | 9.9 | 10.2[b] | 8.1[a] | 10.0[abc] | 10.7 | 11.4[b] | - | 10.8[bc] | 7.1 | 7.4[b] | 7.6[a] | 7.8[abc] |
| pH | 8.0 | - | 8.1[a] | 8.1[a] | 7.5 | - | 7.6[a] | 7.6[a] | 7.8 | 7.9[b] | 7.7[a] | 7.74[ab] | 7.9 | - | - | - |
| COD (mg/ℓ) | 63 | - | 75[a] | 75[a] | 100 | 106[b] | 95[a] | 92[abc] | 124 | 100[b] | 83[a] | 81[abc] | 136 | - | - | - |
| Turbidity (NTU) | 2.80 | - | 1.17[a] | 1.17[a] | 2.23 | 1.87[b] | 0.83[a] | 0.59[abc] | 2.28 | - | - | - | 2.68 | 1.78[b] | 1.58[a] | 0.68[ab] |
| $NO_2$ (µg/ℓ) | 1.7 | - | - | - | 3.4 | 7.3[b] | 1.1[a] | 1.3[abc] | 2.2 | 2.7[b] | - | 3.2[bc] | 0.9 | - | - | - |
| $NO_3$ (mg/ℓ) | 0.023 | - | - | - | 0.027 | 0.035[b] | - | 0.029[bc] | 0.026 | - | - | - | 0.015 | - | - | - |
| $OPO_4$ (mg/ℓ) | 0.005 | - | .008[a] | .008[a] | 0.011 | 0.009[b] | 0.019[a] | 0.020[abc] | - | - | - | - | 0.014 | 0.009[b] | 0.018[a] | 0.013[ab] |
| TP (mg/ℓ) | 0.046 | - | .039[a] | .039[a] | 0.025 | 0.018[b] | 0.017[a] | 0.011[ab] | 0.028 | - | 0.035[a] | 0.035[a] | 0.037 | 0.033[b] | 0.030[a] | 0.026[ab] |
| TKN (mg/ℓ) | 0.290 | - | - | - | 0.177 | - | - | - | 0.433 | 0.453[b] | 0.302[a] | 0.302[ab] | 0.289 | - | 0.181[a] | 0.181[a] |
| $NH_3$ (mg/ℓ) | 0.209 | - | 0.095[a] | 0.095[a] | 0.011 | - | 0.018[a] | 0.018[a] | 0.219 | - | 0.272[a] | 0.272[a] | 0.016 | 0.010[b] | - | 0.010[b] |
| SS (mg/ℓ) | 17.23 | 12.31[b] | 11.63[a] | 11.90[abc] | 13.54 | 12.47[b] | - | 13.37[bc] | 13.05 | - | 14.30[a] | 12.67[ac] | 13.1 | 10.8[b] | 10.3[a] | 11.0[abc] |
| VNR (mg/ℓ) | 4.56 | - | - | 5.34[c] | 4.18 | - | - | 4.75[c] | 5.11 | - | 5.93[a] | 5.03[ac] | 3.3 | - | - | - |
| Chlorophyll *a* (µg/ℓ) | 8.4 | - | 6.3[a] | 7.0[ac] | 11.7 | - | 7.4[a] | 5.2[ac] | 20.2 | 31.4[b] | 7.5[a] | 13.2[abc] | 4.0 | 5.0[b] | 1.7[a] | 1.2[abc] |
| Chlorophyll *b* (µg/ℓ) | 0.5 | - | 0.4[a] | 0.5[ac] | 0.6 | 0.5[b] | 0.3[a] | 0.2[ab] | 1.2 | - | 0.7[a] | 0.7[a] | 0.4 | - | 0.1[a] | 0.1[a] |
| Chlorophyll *c* (µg/ℓ) | 3.0 | - | 2.4[a] | 2.6[ac] | 4.1 | - | 2.7[a] | 1.9[ac] | 3.9 | 6.28[b] | 2.8[a] | 4.4[abc] | 1.7 | - | 0.7[a] | 0.5[ac] |
| Phaeophytin (µg/ℓ) | 0.6 | - | 0.0[a] | 0.0[a] | 1.2 | - | 0.0[a] | 0.0[a] | 4.5 | 6.0[b] | 1.5[a] | 1.6[abc] | 0.8 | - | 0.1[a] | 0.1[a] |

| December 1983 | February 1984 | May 1984 | August 1984 |
|---|---|---|---|
| Multivariate Model: | Multivariate Model: | Multivariate Model: | Multivariate Model: |
| Site: $F$=71.29 (19.34); $P$<0.001 | Site: $F$=700.05 (19,33); $P$<0.001 | Site: $F$=103.96 (18,34); $P$<0.001 | Site: $F$=98.24 (19,31); $P$<0.001 |
| Depth: $F$=3.87 (19,34); $P$<0.001 | Depth: $F$=15.09 (19,33); $P$<0.001 | Depth: $F$=23.85 (18,34); $P$<0.001 | Depth: $F$=25.18 (19,31); $P$<0.001 |
| Site x Depth: $F$=7.68 (19,34); $P$<0.001 | Site x Depth: $F$=15.30 (19,33); $P$<0.001 | Site x Depth: $F$=16.99 (18,34); $P$<0.001 | Site x Depth: $F$=16.32 (19,31); $P$<0.001 |

Notes: Effect not different at the $\alpha$=0.01 level (i.e. same as default value - DNS bottom; or zero if DNS value is not significant).

a) Site effect significant at the $\alpha$=0.01 level.
b) Depth effect significant at the $\alpha$=0.01 level.
c) Site x depth effect significant at the $\alpha$=0.01 level.

TABLE 3. Results of multiple regression analysis models of month to month, geographic and depth effects on the major PCA factors. Only those values which were significant at the $\alpha$=0.01 level were selected. The direction of the effect (+ or -) and the contribution of the effect to the total variance ($R^2$) are indicated.

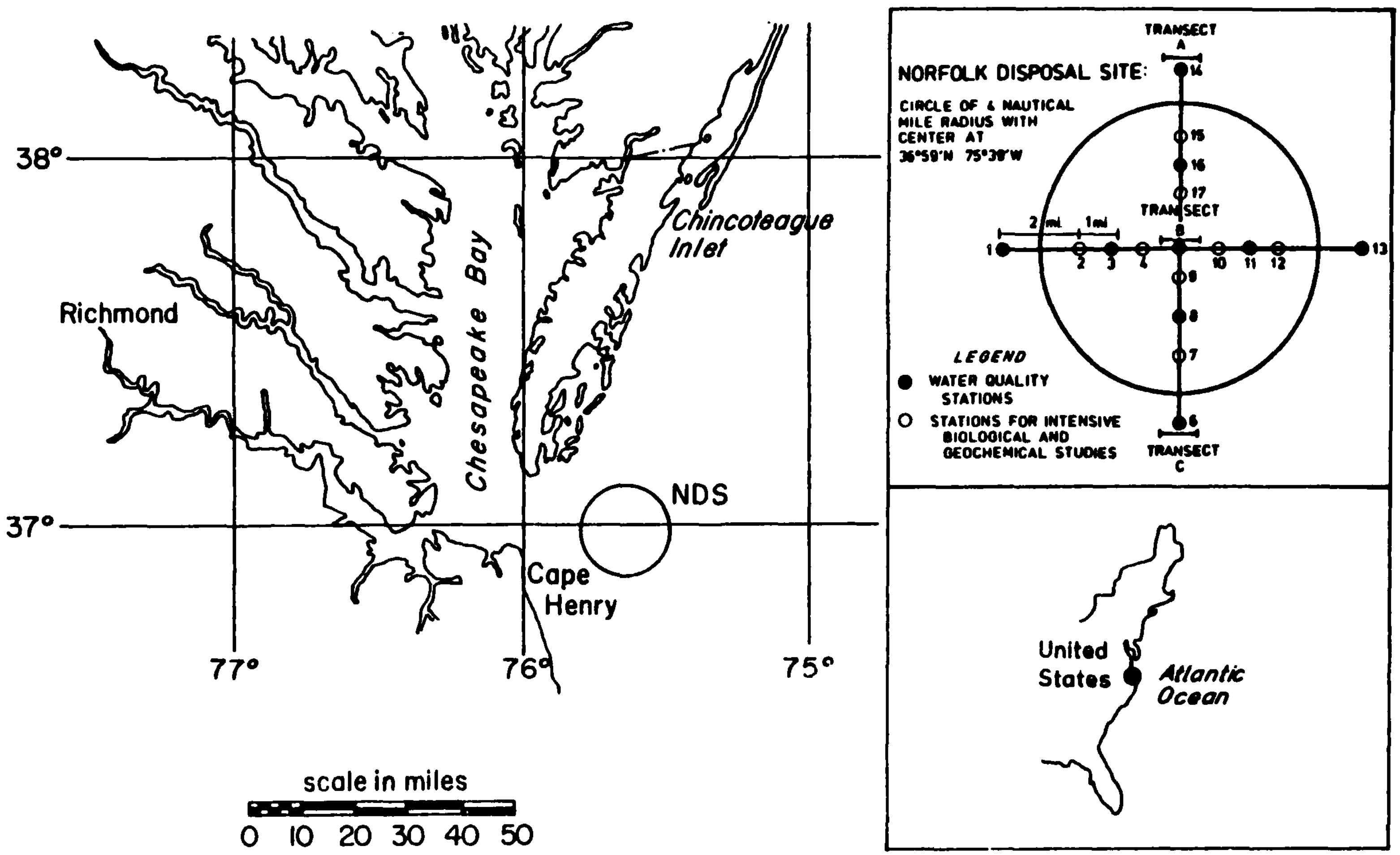
| Dependent Variables Factors/Loading | Independent Variables ($R^2$;P) | | | |
|---|---|---|---|---|
| | Fall | Winter | Spring | Summer |
| PCA 1 (23.4%):<br>(+: chlorphylls, DO, VNR)<br>(-: salinity, temperature) | $(Month)^2$(+;.34;<0.001) | NS by WE by depth (-;.22;<0.001)<br>Month (+;.20;<0.001) | $(Month)^2$(-;.29;<0.001)<br>WE by depth (-;.17;<0.001) | WE (-;.32;<0.001) |
| PCA 2 (17%):<br>(+: SS, VNR, salinity, turbidity, $NH_3$)<br>(-: temperature, pH, TKN, $NO_2$, COD) | $(Month)^2$ by depth (+;.26;<0.001) | Month by depth (+;.48;<0.001) | Depth (+;.33;<0.001) | $(Month)^2$(-;.57;<0.001)<br>Month by depth (+;.23;<0.001) |
| PCA 3 (15.1%):<br>(+: temperature, TP, TKN, SS, pH)<br>(-: DO) | $(Month)^2$ by depth (+;.18;<0.001) | Month by depth (+;.23;<0.001)<br>$(Month)^2$(+;.12;<0.003)<br>Depth (+;.12;<0.003)<br>WE by depth (-;.11,<0.001) | WE (-;.37;<0.001)<br>WE by depth (-;.06;<0.001) | Month (+;.31;<0.001)<br>WE (-;.24;<0.001) |
| PCA 4 (8.2%):<br>(+: salinity)<br>(-: nitrate-nitrites) | | Month by depth (-;.50;<0.001)<br>$(Month)^2$(+;.15;<0.001)<br>Depth (+;.16;<0.001) | Depth (+;.23;<0.001)<br>$(Month)^2$ by depth (-;08;<0.005) | WE by depth (+;.31;<0.001)<br>Month (-;.24;<0.001) |
| PCA 5 (7.2%):<br>(+: salinity, $NO_2$, chlorophyll b) | NS (-;.25;<0.001) | Month+$(Month)^2$(+/-;.37;<0.001) | Depth (+;.57;<0.001)<br>$(Month)^2$(-;.10;<0.001) | $(Month)^2$(+;.44;<0.001)<br>$(Month)^2$ by depth (+;.19;<0.001) |
| PCA 6 (5.8%):<br>(+: chlorophyll b)<br>(-: chlorophyll c) | | Month (-;.25;<0.001)<br>WE (+;.15;<0.001) | | $(Month)^2$(-;.26;<0.001) |

TABLE 4. The estimated MDI's for water quality parameters at the Norfolk Disposal Site. The MDI values represent the percent change (+ for parameters expected to be enhanced; - for parameters expected to be decreased) estimated to be necessary to produce a statistically significant difference ($\alpha$=0.001) from seasonal mean values of the parameters. The values in parentheses represent the absolute "impacted" values resulting from such a change (units are the same as in Figs. 2-4).

| | MDI's | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Season-Area Interaction Model | | | | | Single Sample Model | | | |
| | Fall | Winter | Spring | Summer | Summer | Fall | Winter | Spring | Summer |
| Parameter | MDI ($\bar{x}$) | MDI ($\bar{x}$) | MDI ($\bar{x}$) | MDI ($\bar{x}$) | MDI ($\alpha$=0.05) | MDI ($\bar{x}$) | MDI ($\bar{x}$) | MDI ($\bar{x}$) | MDI ($\bar{x}$) |
| D.O. | - 5(8.3) | - 5(10.1) | - 5(8.6) | - 5(6.3) | - 5 | - 15(7.4) | - 25(8.3) | - 60(3.9) | - 45(3.6) |
| pH | - 5(7.5) | - 5(2.3) | - 5(7.3) | - 5(7.3) | - 5 | - 5(7.5) | - 15(6.4) | - 15(6.6) | - 10(7.1) |
| COD | +155(174) | + 5(80) | + 5(163) | + 20(141) | + 5 | +170(247) | + 65(143) | + 60(242) | + 65(189) |
| Turbidity | + 5(3.43) | + 25(4.85) | + 5(2.06) | + 90(5.37) | + 5 | +170(11.06) | +135(8.7) | +195(6.04) | +195(9.68) |
| $NO_2$ | + 85(.003) | +100(0.010) | +190(0.002) | +360(0.019) | +200 | +150(0.006) | +875(0.036) | +475(0.006) | +160(0.013) |
| $NO_3$ | +360(0.197) | +120(0.083) | + 5(0.017) | + 70(0.029) | + 5 | +440(0.219) | +250(0.153) | +355(0.088) | +160(0.045) |
| $OPO_4$ | BDL | 170(0.018) | <1000(<0.012) | +100(0.035) | + 30 | +655(0.008) | +395(0.023) | +1435(0.021) | +125(0.035) |
| TP | + 5(.065) | + 5(0.034) | + 5(0.033) | + 25(0.057) | + 5 | + 65(0.085) | +110(0.068) | +155(0.075) | +110(0.106) |
| TKN | + 5(0.262) | + 5(0.271) | + 5(0.278) | + 5(0.360) | + 5 | + 20(0.386) | + 55(0.648) | + 40(0.586) | + 35(0.642) |
| $NH_3$ | + 5(.299) | +105(0.248) | + 5(0.156) | +225(0.199) | + 85 | +145(0.626) | +345(0.329) | +120(0.389) | +195(0.234) |
| S.S. | + 15(30.09) | + 10(12.55) | + 5(13.45) | + 70(20.95) | + 5 | +130(47.81) | +130(32.30) | +125(28.75) | +105(25.38) |
| VNR | + 15(4.94) | + 5(4.97) | + 5(4.55) | + 20(4.42) | + 5 | +110(9.90) | +150(10.74) | +155(11.84) | +130(7.88) |
| Chlorophyll *a* | -155(<0) | -240(<0) | -450(<0) | -325(<0) | - 5 | -300(<0) | - 65(4.11) | - 10(14.89) | -150(<0) |
| Chlorophyll *b* | -220(<0) | -305(<0) | -380(<0) | -210(<0) | - 5 | -115(<0) | -210(<0) | -210(<0) | -175(<0) |
| Chlorophyll *c* | -155(<0) | -265(<0) | -290(<0) | -235(<0) | - 5 | -350(<0) | - 95(0.19) | -170(<0) | -140(<0) |
| Phaeophytin | +130(1.86) | +410(10.3) | +100(4.07) | +425(8.90) | +260 | +330(3.76) | +695(13.78) | + 60(4.84) | +910(16.69) |

Note: BDL - At least one cell in the model contains all values which are below detection limits.

Figure 1. Proposed Norfolk Disposal Site (NDS)



38°
37°
77°
76°
75°
Richmond
Chesapeake Bay
Chincoteague Inlet
NDS
Cape Henry
scale in miles
0 10 20 30 40 50
NORFOLK DISPOSAL SITE:
CIRCLE OF 4 NAUTICAL MILE RADIUS WITH CENTER AT 36°59'N 75°39'W
TRANSECT A
TRANSECT B
TRANSECT C
2 mi
1 mi
1 2 3 4 10 11 12 13
14 15 16 17 9 8 7 6
LEGEND
WATER QUALITY STATIONS
STATIONS FOR INTENSIVE BIOLOGICAL AND GEOCHEMICAL STUDIES
United States
Atlantic Ocean

Figure 2. Interim disposal site off Dam Neck, VA.

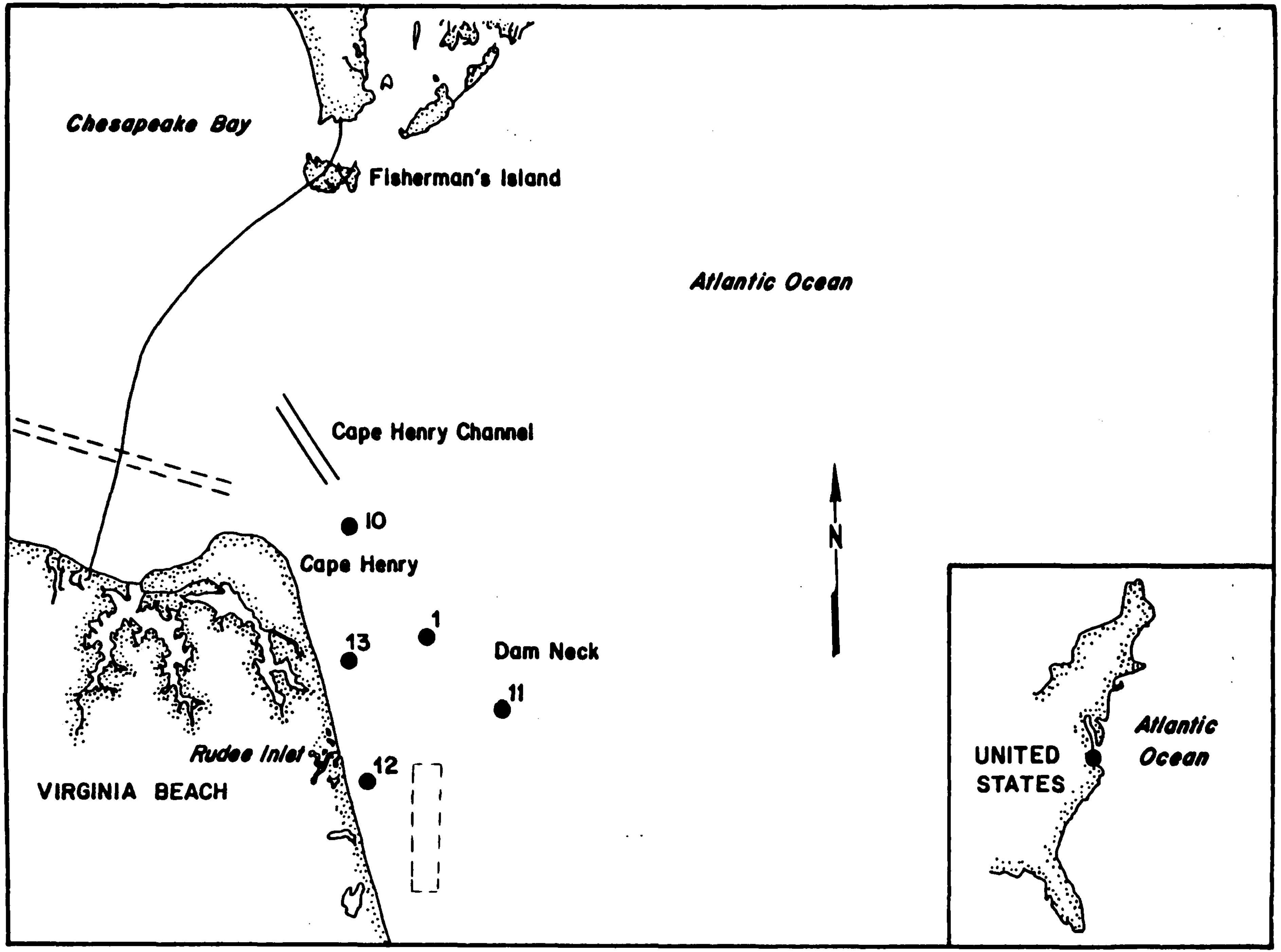
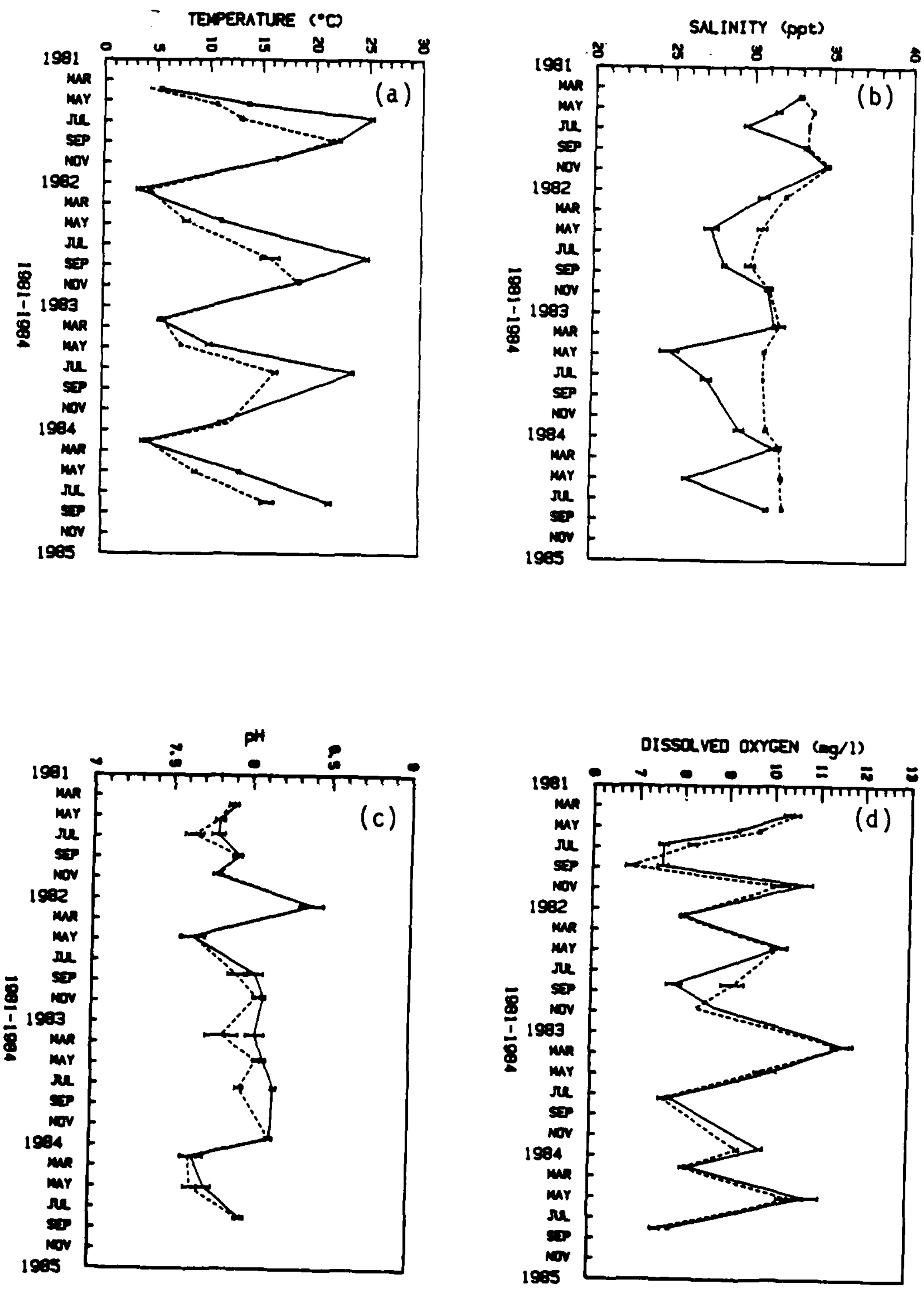

Chesapeake Bay
Fisherman's Island
Atlantic Ocean
Cape Henry Channel
10
Cape Henry
N
1
13
Dam Neck
11
Rudee Inlet
12
VIRGINIA BEACH
UNITED STATES
Atlantic Ocean

Figure 3. Physical parameters monitored at the proposed Norfolk Disposal Site (NDS) for 1981-1984. Solid lines represent surface values and broken lines are bottom measurements: a) temperature ($^{o}C$), b) salinity ($^{o}/oo$), c) pH, and d) dissolved oxygen (DO) (mg/l).



TEMPERATURE (°C)
(a)
SALINITY (ppt)
(b)
pH
(c)
DISSOLVED OXYGEN (mg/l)
(d)
1981-1984
1981
MAR
MAY
JUL
SEP
NOV
1982
1983
1984
1985

Figure 4. Physical and chemical parameters monitored at the proposed Norfolk Disposal Site (NDS) for 1981-1984: a) suspended solids (SS) (mg/g), b) volatile residue (VNR) (mg/l), c) chemical oxygen demand (COD) (mg/l), and d) turbidity (NTU).

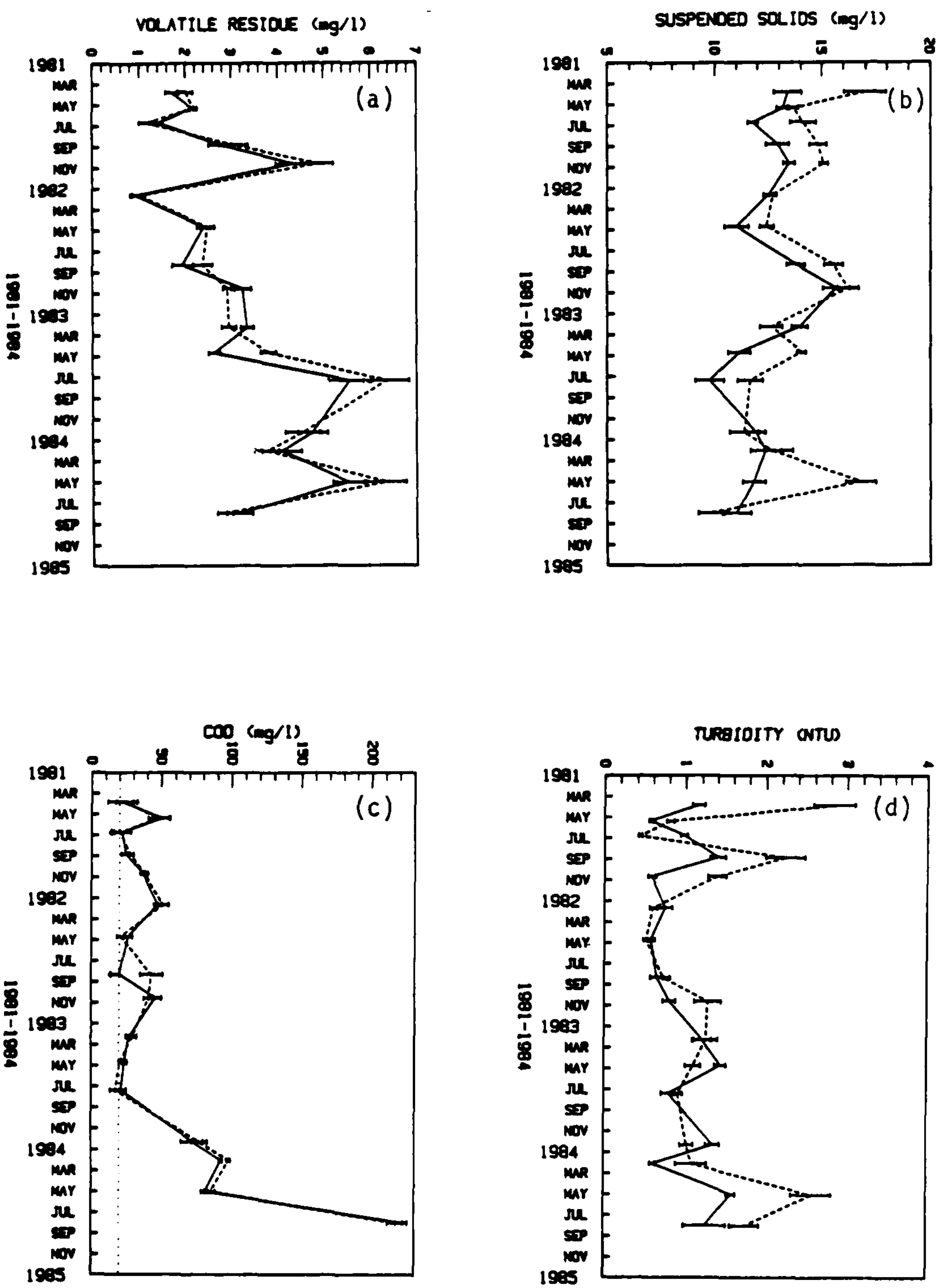
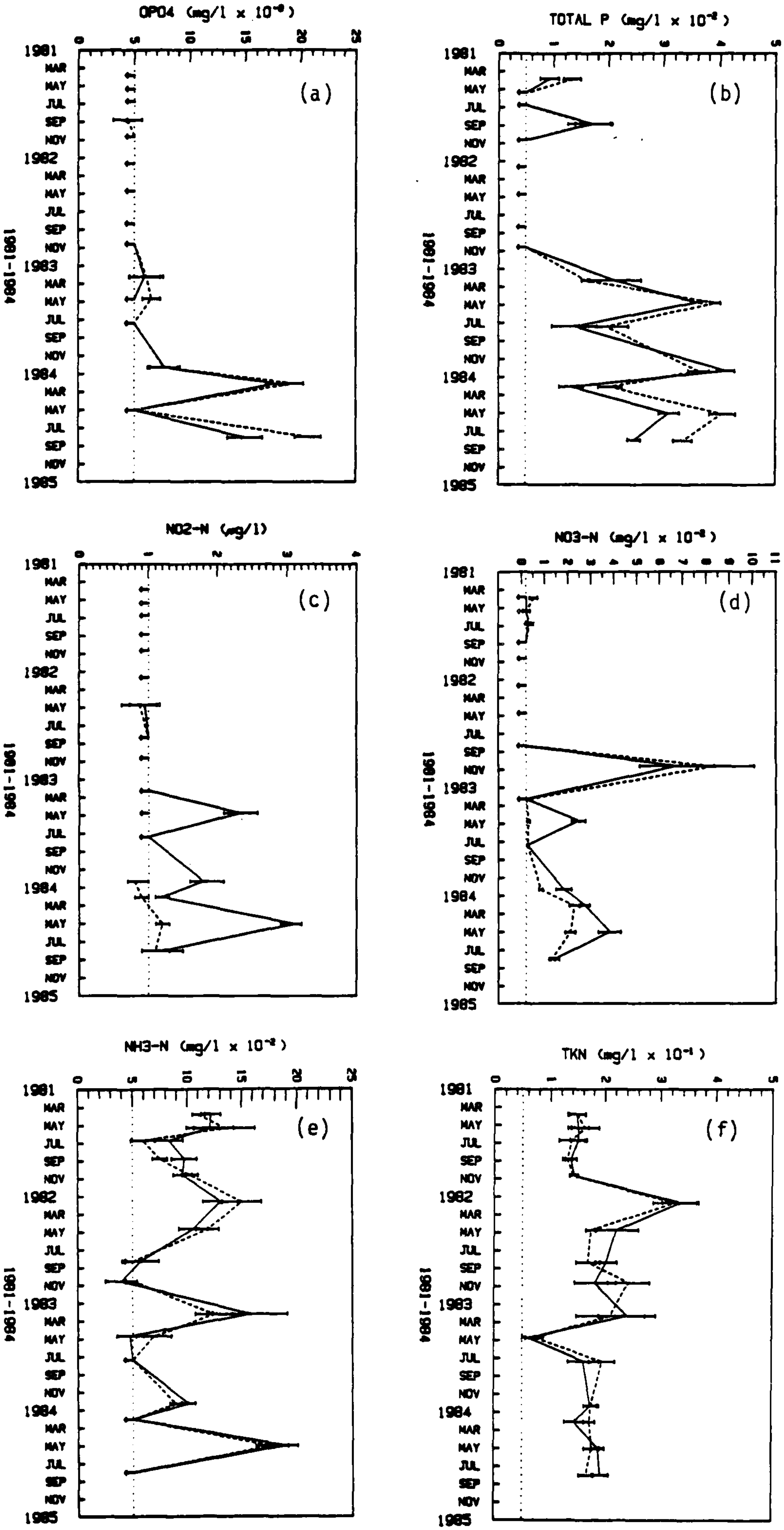
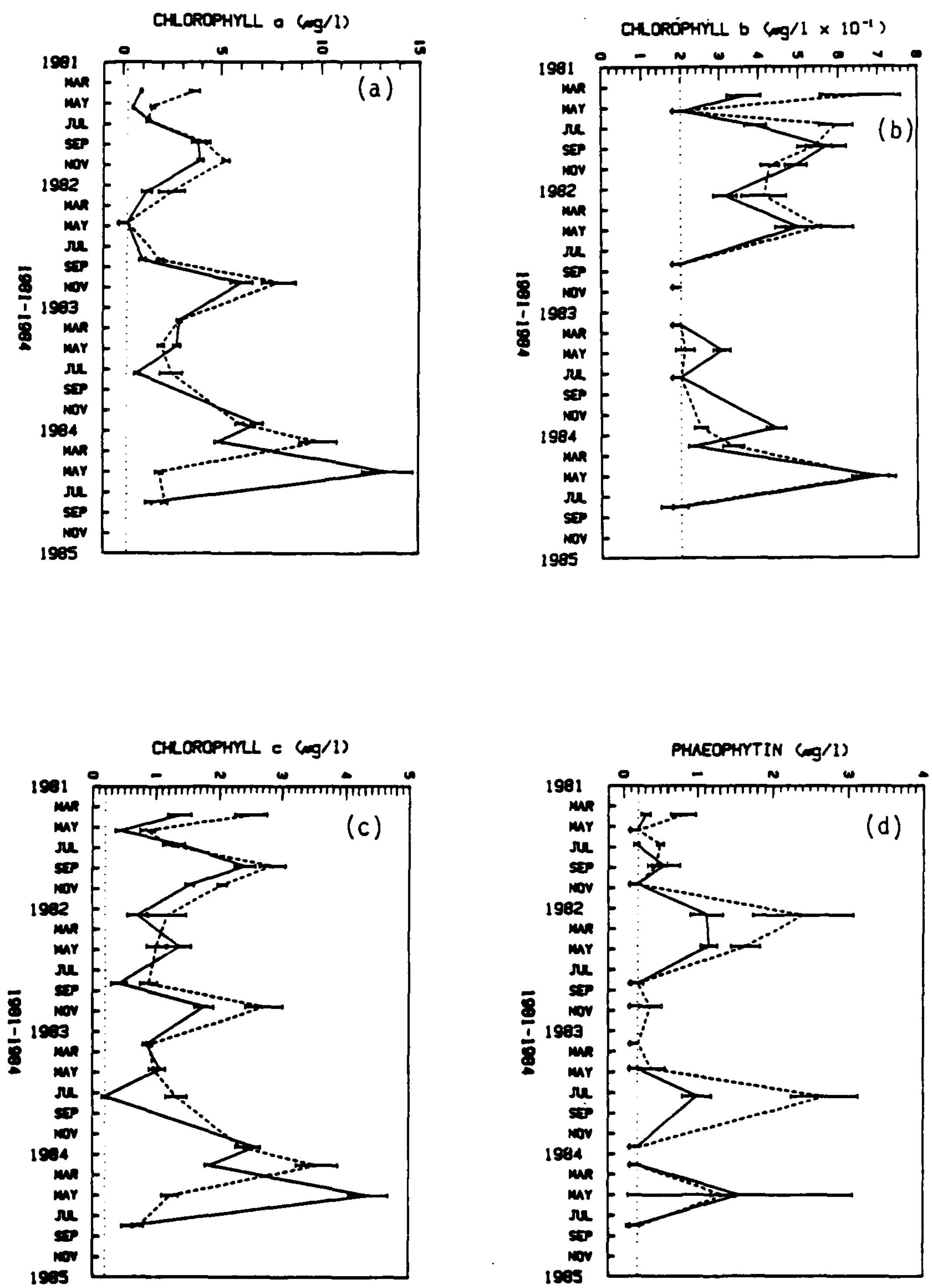

VOLATILE RESIDUE (mg/l)
(a)
SUSPENDED SOLIDS (mg/l)
(b)
COD (mg/l)
(c)
TURBIDITY (NTU)
(d)
1981-1984
1981
MAR
MAY
JUL
SEP
NOV
1982
1983
1984
1985

Figure 5. Nutrient parameters monitored at the proposed Norfolk Disposal Site (NDS) for 1981-1984: a) orthophosphates ($OPO_4$-P) (mg/l$\times10^{-3}$), b) phosphorous (mg/l$\times10^{-2}$), c) nitrite ($NO_2$-N) (µg/l), d) nitrate ($NO_3$-N) (mg/l$\times10^{-2}$), e) ammonia ($NH_3$-N), (mg/l$\times10^{-2}$), f) Kjeldhal nitrogen (TKN) (mg/l$\times10^{-1}$).



OPO4
(a)
TOTAL P
(b)
NO2-N (mg/l)
(c)
NO3-N
(d)
NH3-N
(e)
TKN
(f)
1981-1984
1981
1982
1983
1984
1985
MAR
MAY
JUL
SEP
NOV

Figure 6. Chlorophyll and phaeophytin monitored at the Norfolk Disposal Site (NDS) for 1981-1984: a) chlorophyll a ($\mu g/l$), b) chlorophyll b ($\mu g/l \times 10^{-1}$), c) chlorophyll c ($\mu g/l$), and d) phaeophytin ($\mu g/l$).



CHLOROPHYLL a (μg/l)
(a)
CHLOROPHYLL b (μg/l × 10⁻¹)
(b)
CHLOROPHYLL c (μg/l)
(c)
PHAEOPHYTIN (μg/l)
(d)
1981
MAR
MAY
JUL
SEP
NOV
1982
1983
1984
1985
1981-1984

Figure 7. Physical parameters monitored at the Dam Neck Disposal Site (DNDS) for 1984. Solid lines represent surface values, and broken lines are bottom measurements: a) temperature ($^{o}C$), b) salinity ($^{o}/oo$), c) pH, and d) dissolved oxygen (DO) (mg/l).

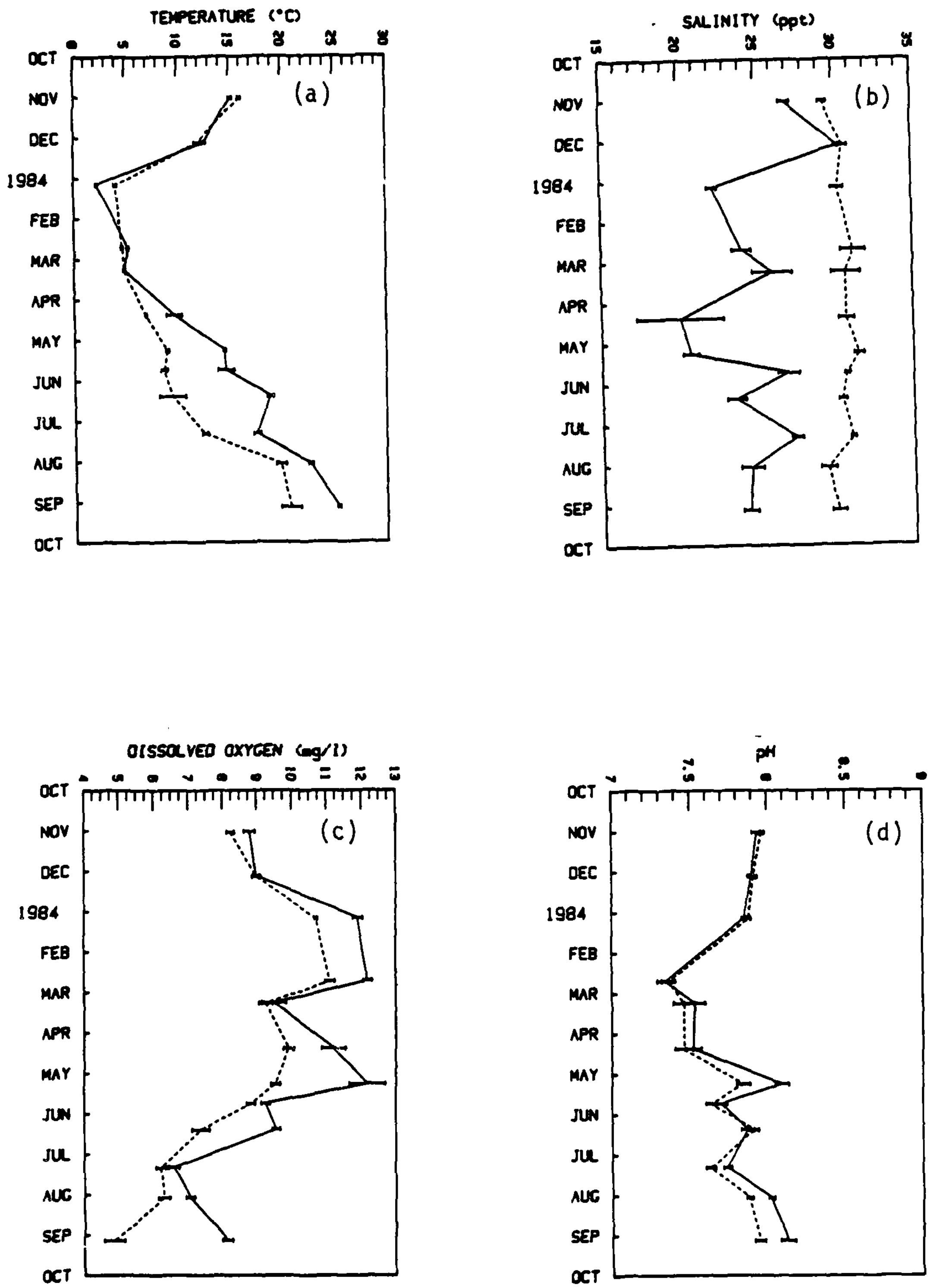
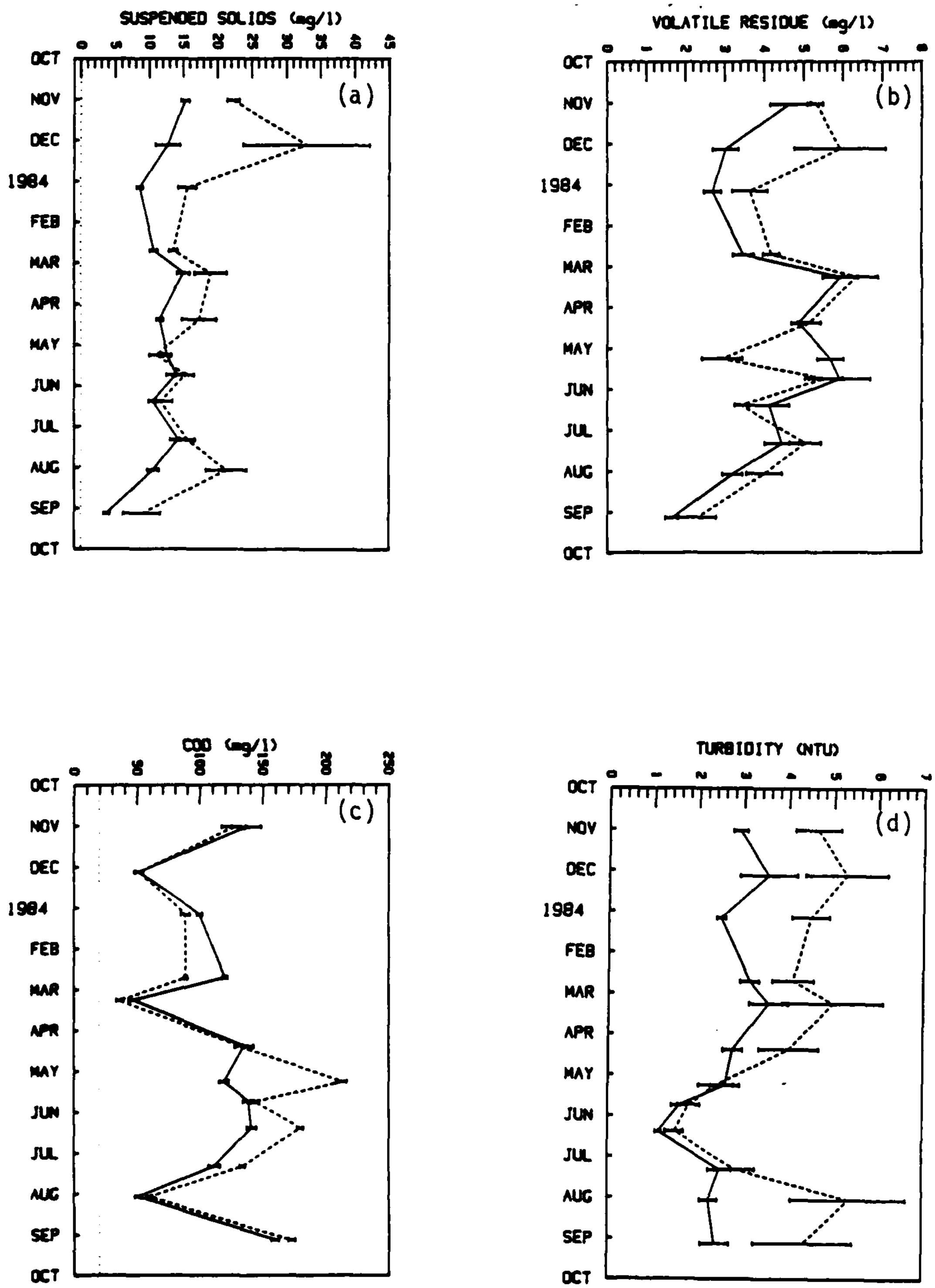
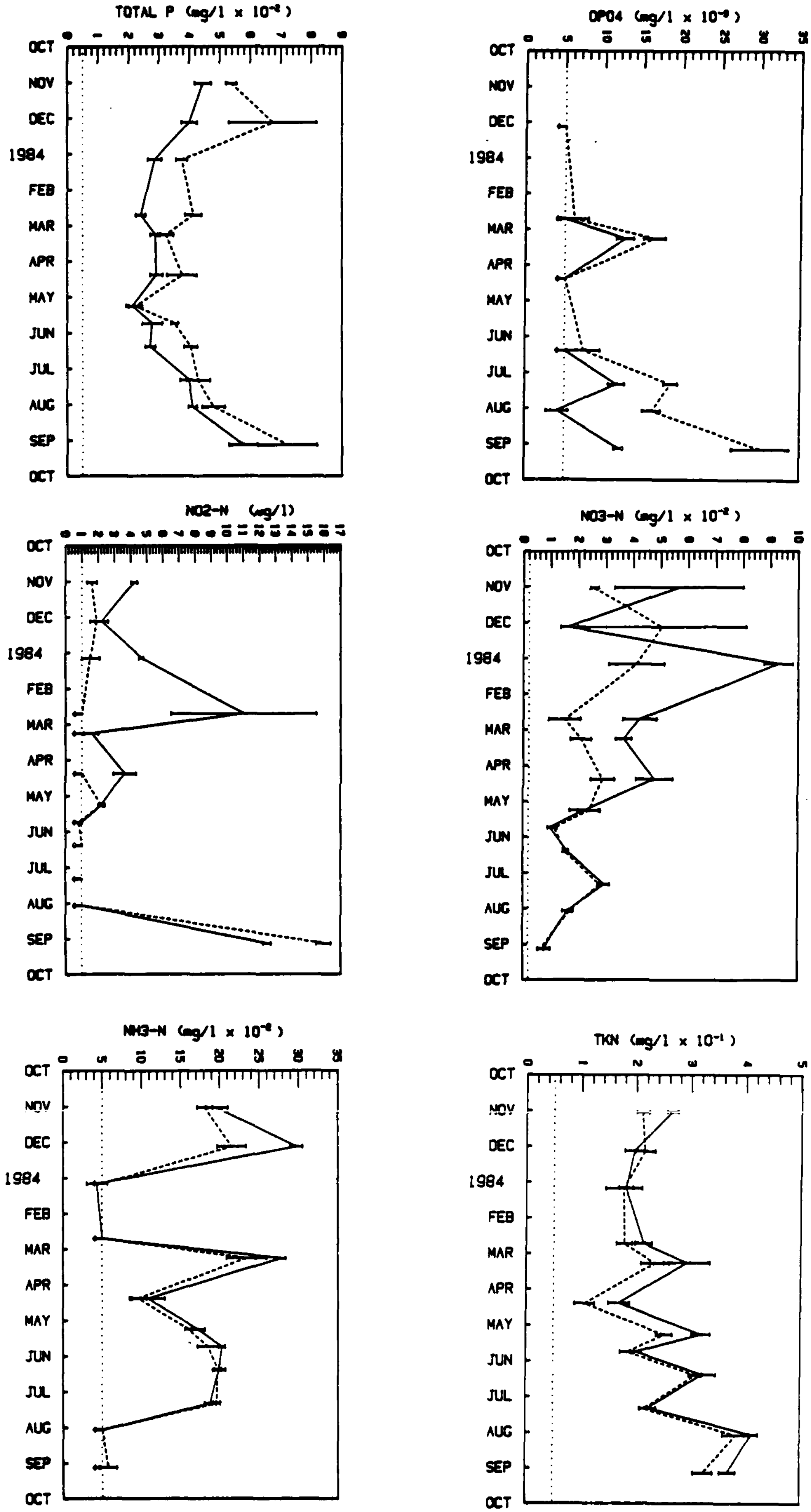

TEMPERATURE (°C)
(a)
SALINITY (ppt)
(b)
DISSOLVED OXYGEN (mg/l)
(c)
pH
(d)
OCT
NOV
DEC
1984
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT

Figure 8. Physical and chemical parameters monitored at Dam Neck Disposal Site (DNDS) for 1984: a) suspended solids (SS) (mg/l), b) volatile residue (VNR) (mg/l), c) chemical oxygen demand (COD) (mg/l), and d) turbidity (NTU).



SUSPENDED SOLIDS (mg/l)
(a)
VOLATILE RESIDUE (mg/l)
(b)
COD (mg/l)
(c)
TURBIDITY (NTU)
(d)
OCT
NOV
DEC
1984
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT

Figure 9. Nutrient parameters monitored at Dam Neck Disposal Site (DNDS) for 1984: a) orthophosphates ($OPO_4$-P) ($mg/l \times 10^{-3}$), b) phosphorous ($mg/l \times 10^{-2}$), c) nitrite ($NO_2$-N) ($\mu g/l$), d) nitrate ($NO_3$-N) ($mg/l \times 10^{-2}$), e) ammonia ($NH_3$-N) ($mg/l \times 10^{-2}$), and f) Kjeldahl nitrogen (TKN) ($mg/l \times 10^{-1}$).



TOTAL P (mg/l x 10⁻²)
OPO4 (mg/l x 10⁻³)
NO2-N (ug/l)
NO3-N (mg/l x 10⁻²)
NH3-N (mg/l x 10⁻³)
TKN (mg/l x 10⁻¹)
OCT
NOV
DEC
1984
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT

Figure 10. Chlorophyll and phaeophytin monitored at Dam Neck Disposal Site (DNDS) for 1984: a) chlorophyll *a* ($\mu g/l$), b) chlorophyll *b* ($\mu g/l \times 10^{-1}$), c) chlorophyll *c* ($\mu g/l$), and d) phaeophytin ($\mu g/l$).

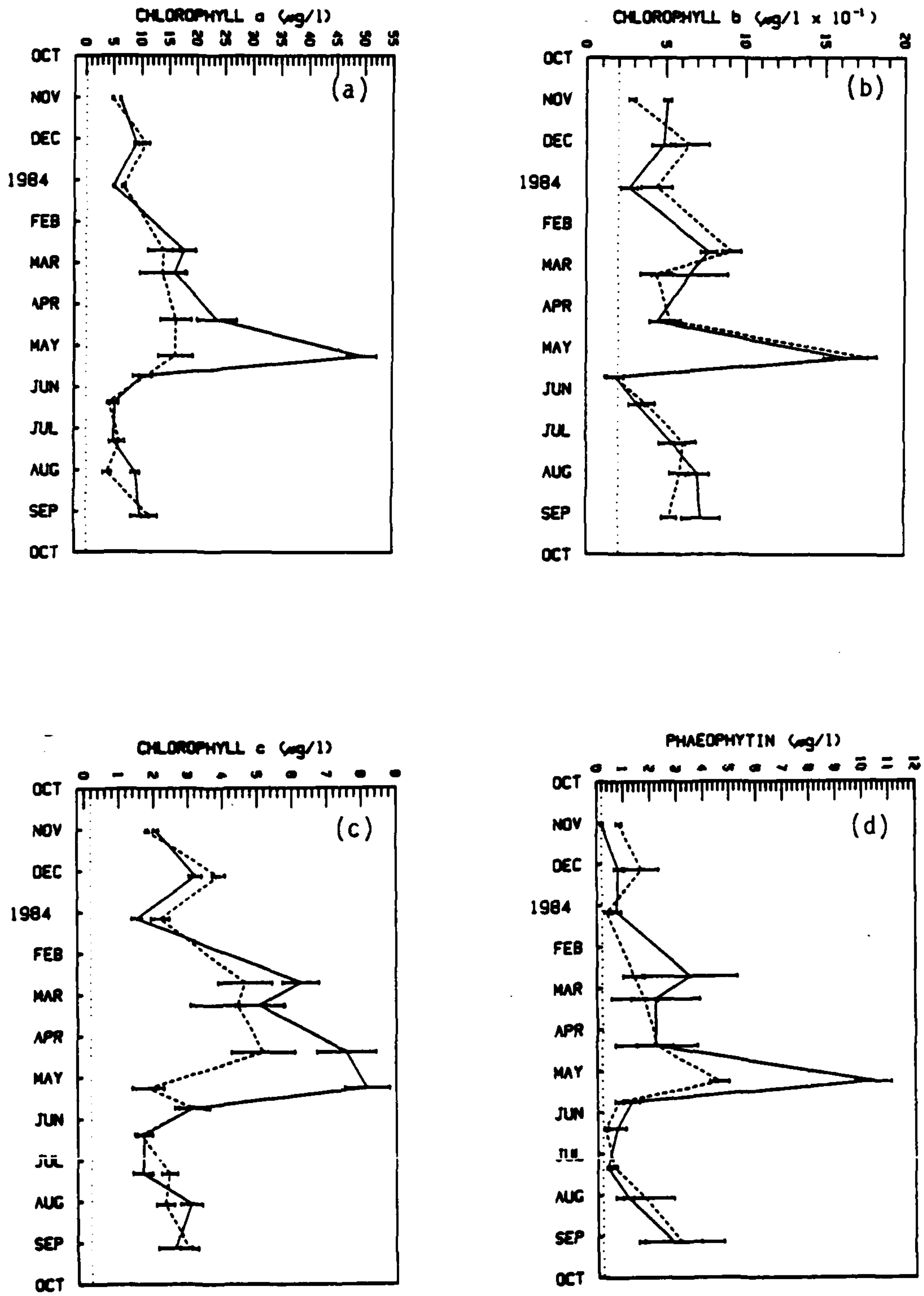
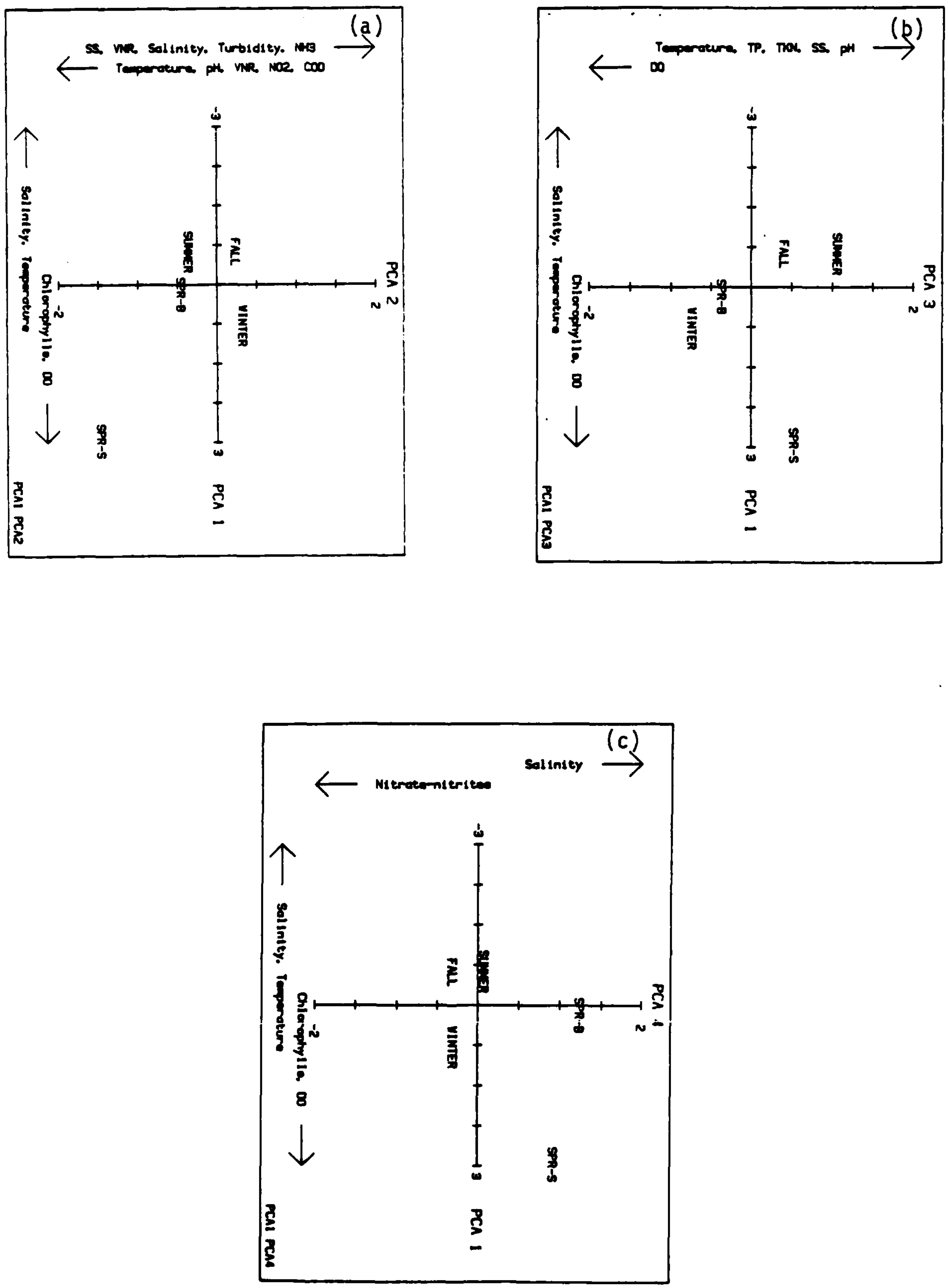

CHLOROPHYLL a (µg/l)
0 5 10 15 20 25 30 35 40 45 50 55
OCT NOV DEC 1984 FEB MAR APR MAY JUN JUL AUG SEP OCT
(a)
CHLOROPHYLL b (µg/l x 10⁻¹)
0 5 10 15 20
(b)
CHLOROPHYLL c (µg/l)
0 1 2 3 4 5 6 7 8 9
(c)
PHAEOPHYTIN (µg/l)
0 1 2 3 4 5 6 7 8 9 10 11 12
(d)

Figure 11. Principal Component Analysis (PCA) summarizing the water quality patterns observed at Dam Neck Disposal Site (DNDS) for 1984. (See text for PCA factor descriptions.)



(a)
SS, VNR, Salinity, Turbidity, NH3
Temperature, pH, VNR, NO2, COD
Salinity, Temperature
Chlorophyll, DO
PCA 1
PCA 2
SUMMER
FALL
SPR-B
WINTER
SPR-S
PCA1 PCA2
(b)
Temperature, TP, TKN, SS, pH
DO
Salinity, Temperature
Chlorophyll, DO
PCA 1
PCA 3
SUMMER
FALL
SPR-B
WINTER
SPR-S
PCA1 PCA3
(c)
Salinity
Nitrate-nitrites
Salinity, Temperature
Chlorophyll, DO
PCA 1
PCA 4
SUMMER
FALL
SPR-B
WINTER
SPR-S
PCA1 PCA4

DTIC
FILMED
4-86
END